



Height and body-mass index trajectories of school-aged children and adolescents from 1985 to 2019 in 200 countries and territories: a pooled analysis of 2181 population-based studies with 65 million participants

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Abstract: Comparable global data on health and nutrition of school-aged children and adolescents are scarce. We aimed to estimate age trajectories and time trends in mean height and mean body-mass index (BMI), which measures weight gain beyond what is expected from height gain, for school-aged children and adolescents. **Methods:** For this pooled analysis, we used a database of cardiometabolic risk factors collated by the Non-Communicable Disease Risk Factor Collaboration. We applied a Bayesian hierarchical model to estimate trends from 1985 to 2019 in mean height and mean BMI in 1-year age groups for ages 5–19 years. The model allowed for non-linear changes over time in mean height and mean BMI and for non-linear changes with age of children and adolescents, including periods of rapid growth during adolescence. **Findings:** We pooled data from 2181 population-based studies, with measurements of height and weight in 65 million participants in 200 countries and territories. In 2019, we estimated a difference of 20 cm or higher in mean height of 19-year-old adolescents between countries with the tallest populations (the Netherlands, Montenegro, Estonia, and Bosnia and Herzegovina for boys; and the Netherlands, Montenegro, Denmark, and Iceland for girls) and those with the shortest populations (Timor-Leste, Laos, Solomon Islands, and Papua New Guinea for boys; and Guatemala, Bangladesh, Nepal, and Timor-Leste for girls). In the same year, the difference between the highest mean BMI (in Pacific island countries, Kuwait, Bahrain, The Bahamas, Chile, the USA, and New Zealand for both boys and girls and in South Africa for girls) and lowest mean BMI (in India, Bangladesh, Timor-Leste, Ethiopia, and Chad for boys and girls; and in Japan and Romania for girls) was approximately 9–10 kg/m². In some countries, children aged 5 years started with healthier height or BMI than the global median and, in some cases, as healthy as the best performing countries, but they became progressively less healthy compared with their comparators as they grew older by not growing as tall (eg, boys in Austria and Barbados, and girls in Belgium and Puerto Rico) or gaining too much weight for their height (eg, girls and boys in Kuwait, Bahrain, Fiji, Jamaica, and Mexico; and girls in South Africa and New Zealand). In other countries, growing children overtook the height of their comparators (eg, Latvia, Czech Republic, Morocco, and Iran) or curbed their weight gain (eg, Italy, France, and Croatia) in late childhood and adolescence. When changes in both height and BMI were considered, girls in South Korea, Vietnam, Saudi Arabia, Turkey, and some central Asian countries (eg, Armenia and Azerbaijan), and boys in central and western Europe (eg, Portugal, Denmark, Poland, and Montenegro) had the healthiest changes in anthropometric status over the past 3–5 decades because, compared with children and adolescents in other countries, they had a much larger gain in height than they did in BMI. The unhealthiest changes—gaining too little height, too much weight for their height compared with children in other countries, or both—occurred in many countries in sub-Saharan Africa, New Zealand, and the USA for boys and girls; in Malaysia and some Pacific island nations for boys; and in Mexico for girls. **Interpretation:** The height and BMI trajectories over age and time of school-aged children and adolescents are highly variable across countries, which indicates heterogeneous nutritional quality and lifelong health advantages and risks.

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Height and body-mass index trajectories of school-aged children and adolescents from 1985 to 2019 in 200 countries and territories: a pooled analysis of 2181 population-based studies with 65 million participants



NCD Risk Factor Collaboration (NCD-RisC)*



Summary

Background Comparable global data on health and nutrition of school-aged children and adolescents are scarce. We aimed to estimate age trajectories and time trends in mean height and mean body-mass index (BMI), which measures weight gain beyond what is expected from height gain, for school-aged children and adolescents.

Methods For this pooled analysis, we used a database of cardiometabolic risk factors collated by the Non-Communicable Disease Risk Factor Collaboration. We applied a Bayesian hierarchical model to estimate trends from 1985 to 2019 in mean height and mean BMI in 1-year age groups for ages 5–19 years. The model allowed for non-linear changes over time in mean height and mean BMI and for non-linear changes with age of children and adolescents, including periods of rapid growth during adolescence.

Findings We pooled data from 2181 population-based studies, with measurements of height and weight in 65 million participants in 200 countries and territories. In 2019, we estimated a difference of 20 cm or higher in mean height of 19-year-old adolescents between countries with the tallest populations (the Netherlands, Montenegro, Estonia, and Bosnia and Herzegovina for boys; and the Netherlands, Montenegro, Denmark, and Iceland for girls) and those with the shortest populations (Timor-Leste, Laos, Solomon Islands, and Papua New Guinea for boys; and Guatemala, Bangladesh, Nepal, and Timor-Leste for girls). In the same year, the difference between the highest mean BMI (in Pacific island countries, Kuwait, Bahrain, The Bahamas, Chile, the USA, and New Zealand for both boys and girls and in South Africa for girls) and lowest mean BMI (in India, Bangladesh, Timor-Leste, Ethiopia, and Chad for boys and girls; and in Japan and Romania for girls) was approximately 9–10 kg/m². In some countries, children aged 5 years started with healthier height or BMI than the global median and, in some cases, as healthy as the best performing countries, but they became progressively less healthy compared with their comparators as they grew older by not growing as tall (eg, boys in Austria and Barbados, and girls in Belgium and Puerto Rico) or gaining too much weight for their height (eg, girls and boys in Kuwait, Bahrain, Fiji, Jamaica, and Mexico; and girls in South Africa and New Zealand). In other countries, growing children overtook the height of their comparators (eg, Latvia, Czech Republic, Morocco, and Iran) or curbed their weight gain (eg, Italy, France, and Croatia) in late childhood and adolescence. When changes in both height and BMI were considered, girls in South Korea, Vietnam, Saudi Arabia, Turkey, and some central Asian countries (eg, Armenia and Azerbaijan), and boys in central and western Europe (eg, Portugal, Denmark, Poland, and Montenegro) had the healthiest changes in anthropometric status over the past 3·5 decades because, compared with children and adolescents in other countries, they had a much larger gain in height than they did in BMI. The unhealthiest changes—gaining too little height, too much weight for their height compared with children in other countries, or both—occurred in many countries in sub-Saharan Africa, New Zealand, and the USA for boys and girls; in Malaysia and some Pacific island nations for boys; and in Mexico for girls.

Interpretation The height and BMI trajectories over age and time of school-aged children and adolescents are highly variable across countries, which indicates heterogeneous nutritional quality and lifelong health advantages and risks.

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Introduction

Growth and development through childhood and adolescence are affected by social, nutritional, and environmental factors at home, at school, and in the

community. During school ages (typically 5–19 years), these factors amplify or mitigate adversity in infancy and early childhood and, if healthy, can help consolidate gains from early childhood and correct some nutritional

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See Online for appendix

Research in context

Evidence before this study

We searched MEDLINE (through PubMed) for articles published from inception up to Aug 2, 2020, with no language restrictions, using the following search terms: ("body size"[mh:noexp] OR "body height"[mh:noexp] OR "body weight"[mh:noexp] OR "birth weight"[mh:noexp] OR "overweight"[mh:noexp] OR "obesity"[mh] OR "thinness"[mh:noexp] OR "Waist-Hip Ratio"[mh:noexp] OR "Waist Circumference"[mh:noexp] OR "body mass index"[mh:noexp]) AND ("Humans"[mh]) AND ("Health Surveys"[mh] OR "Epidemiological Monitoring"[mh] OR "Prevalence"[mh]) NOT Comment[ptyp] NOT Case Reports[ptyp]. Articles were screened according to the inclusion and exclusion criteria described in the Methods section. We found global or multicountry studies on trends over time in height for adults and for children younger than 5 years, but not for school-aged children and adolescents. One multicountry study used cross-sectional height data in 53 community-based samples and reported height differences in children aged 10–17 years. We found three studies on trends in body-mass index (BMI) or overweight in children and adolescents, but only one of these studies separately reported trends for children aged 5–19 years. We found multiple studies in individual or small groups of countries on trends in height, BMI, or both. In terms of considering combined changes in height and BMI, the *Lancet* Series on the double burden of malnutrition used data on

stunting in children younger than 5 years together with data on various measures of underweight and overweight at different ages, but did not have data on height in older children and adolescents, nor did it analyse trends.

Added value of this study

To our knowledge, this study presents the first comparable estimates of height in school-aged children and adolescents for all countries in the world and does so alongside estimates of BMI, which together are pathways from nutrition and environment during childhood and adolescence to lifelong health. We also analysed age trajectories of mean height and BMI to investigate ages when growth in different countries was more versus less healthy and to identify the need for intervention.

Implications of all the available evidence

Age trajectories and time trends in mean height and BMI of school-aged children and adolescents were highly variable across countries and indicated heterogeneous nutritional quality and life-long health advantages and risks. Global and national nutrition and health programmes should extend to children and adolescents in school years to consolidate gains in children younger than 5 years and enable healthy growth through the entire developmental period.

inadequacies and imbalances.^{1–3} Therefore, investing in the nutrition of school-aged children and adolescents is crucial for a healthy transition to adulthood.

Height and body-mass index (BMI) are anthropometric measures of the quality of nutrition and healthiness of the living environment during childhood and adolescence and are highly predictive of health and developmental outcomes throughout life.^{4–7} Having low height and excessively low weight for one's height, represented by low BMI, increases the risk of morbidity and mortality, impairs cognitive development, and reduces educational performance and work productivity in later life.^{4,5,7} High BMI is associated with higher risk of disability and premature death in adulthood and with poor mental health and educational outcomes.^{6,8}

Much of global health and nutrition research and policy has focused on the period from preconception to age 5 years.^{9,10} For school-aged children and adolescents, global information is available only for BMI¹¹ and, to our knowledge, no study has reported global trends in height for these ages. In this study, we present consistent and comparable global estimates of height and BMI for school-aged children from 1985 to 2019 and assess how countries perform in terms of children and adolescents growing taller without excessive weight gain. We also evaluate height and BMI trajectories by age to understand when growth is more or less healthy and to identify the need for intervention.

Methods

Data sources

For this pooled analysis, we used a database of cardio-metabolic risk factors collated by the Non-Communicable Disease Risk Factor Collaboration (NCD-RisC). The database and its criteria for data inclusion and exclusion are described in the appendix (pp 39–42). We used data from the NCD-RisC database from 1985 to 2019 for analysis of BMI and from 1971 to 2019 for analysis of height. Children aged 5 years in data from 1971 were born in 1966, and hence were 19 years old in 1985, as were children aged 6 years in data from 1972 through to 19-year-old adolescents in data from 1985. Additionally, for analysis of height, participants aged 20–30 years were included and assigned to their corresponding birth cohort, because mean height in these ages would be at least that when they were aged 19 years, given that the decline of height with age begins in the third and fourth decades of life. The inclusion of data from different years provided multiple observations of each birth cohort during their life course, which in turn helped to estimate the relevant parameters in the height model that used birth year as its time scale. A list of the data sources we used in this analysis and their characteristics is provided in the appendix (pp 49–89).

Primary outcomes

Our primary outcomes were population mean height and mean BMI from ages 5 to 19 years. BMI accounts for

the weight gain that is simply due to becoming taller, and hence measures being underweight or overweight for a person's height. When presenting results, we refer to gains in height as a healthy trend because the relationship between height and health is positive and continuous. We refer to BMI gain as unhealthy except in countries where mean BMI was more than 1 SD lower than the median of the WHO reference (ie, lower than 18.7 kg/m² for girls and 19.6 kg/m² for boys at age 19 years). We also compared mean height and BMI with the median of the WHO growth reference¹² (appendix pp 90–93) at each age from 5 to 19 years. We used the WHO reference because it provides growth curves for both height and BMI and is used for monitoring in most countries. We started our analysis from age 5 years because children enter school at or around this age, and their nutrition, physical activity, and health are influenced by food and environment at their homes, schools, and communities.

Statistical analysis

We used a Bayesian hierarchical model to estimate mean height and mean BMI by country, year, sex, and age. The model is described in detail in a statistical paper¹³ and related substantive papers^{11,14} and is summarised in the appendix (pp 43–45). Briefly, the model had a hierarchical structure in which estimates for each country and year were informed by its own data, if available, and by data from other years in the same country and from other countries, especially those in the same region and super-region, with data for similar time periods. The extent to which estimates for each country-year were influenced by data from other years and other countries depended on whether the country had data, the sample size of the data, whether they were national, and the within-country and within-region variability of the available data.

The model allowed for non-linear time trends and non-linear changes in mean height and BMI with age, including periods of rapid growth during puberty, and the earlier age of these growth spurts in girls than in boys. We used observation year—the year in which data were collected—as the time scale for the analysis of BMI and birth year as the time scale for the analysis of height, consistent with previous analyses.^{11,14} For BMI, substantial societal changes that affect nutrition and physical activity might affect children of different ages simultaneously, whereas for height, these effects accumulate in each birth cohort and a cohort's height-for-age monotonically increases from childhood to late adolescence.

The computer code for the model is available online, as are our country and regional estimates both in numerical format and as interactive visualisations. All analyses were done with R (version 3.5.1).

Role of the funding source

The funders of the study had no role in study design, data collection, analysis, interpretation, or writing of the

paper. Country and Regional Data Group members, ARM, BZ, and MS had full access to the data in the study. The corresponding author had final responsibility for the decision to submit for publication.

Results

We pooled 2181 population-based measurement surveys and studies, with anthropometric measurements on 50 million people aged 5–19 years and 15 million people aged 20–30 years. We used at least one data source for 193 of 200 countries and territories for which estimates were made, covering 98.7% of the world's population in 2019 (appendix p 94–95), and at least two data sources for 177 countries, covering 98.0% of the world's population. Of these 2181 data sources, 1289 (59.1%) were sampled from national populations, 360 (16.5%) covered one or more subnational regions, and the remaining 532 (24.4%) were from one or a small number of communities. Regionally, data availability ranged from approximately three data sources per country in Oceania to approximately 46 sources per country in the high-income Asia-Pacific region.

In 2019, the 19-year-olds who were on average the tallest in the world lived in northwestern and central European countries: the Netherlands (mean height 183.8 cm, 95% credible interval [CrI] 181.5–186.2), followed by Montenegro, Estonia, and Bosnia and Herzegovina for boys; and the Netherlands (170.4 cm, 168.3–172.4), followed by Montenegro, Denmark, and Iceland for girls (figure 1A). The 19-year-olds who were on average the shortest in 2019 lived in south and southeast Asia, Latin America, and east Africa: Timor-Leste (160.1 cm, 158.0–162.2), followed by Laos, Solomon Islands, and Papua New Guinea for boys; and Guatemala (150.9 cm; 149.4–152.4), followed by Bangladesh, Nepal, and Timor-Leste for girls. The 20 cm or higher difference between countries with the tallest and shortest mean height represents approximately 8 years of growth gap for girls and approximately 6 years for boys. For example, 19-year-old girls in four countries (Guatemala, Bangladesh, Nepal, and Timor-Leste) had the same mean height as that of 11-year-old Dutch girls, and those in another 53 countries—such as Burundi, India, Indonesia, Laos, Pakistan, Peru, the Philippines, and Yemen—had the same mean height as that of 12-year-old Dutch girls (figure 2). Similarly, 19-year-old boys in 11 countries throughout Asia, Latin America, and sub-Saharan Africa had the same mean height as that of Dutch boys aged 13 years.

Although northwestern European children and adolescents were on average the tallest in the world in 2019, much of this advantage was achieved before the late 20th century, and many of these countries had below median height change from 1985 to 2019 (figure 1B, appendix pp 96–296). By contrast, central European countries such as Montenegro and Poland achieved a substantial part of their height advantage since 1985,

For the model code, estimates, and visualisations see <http://www.ncdrisc.org/>

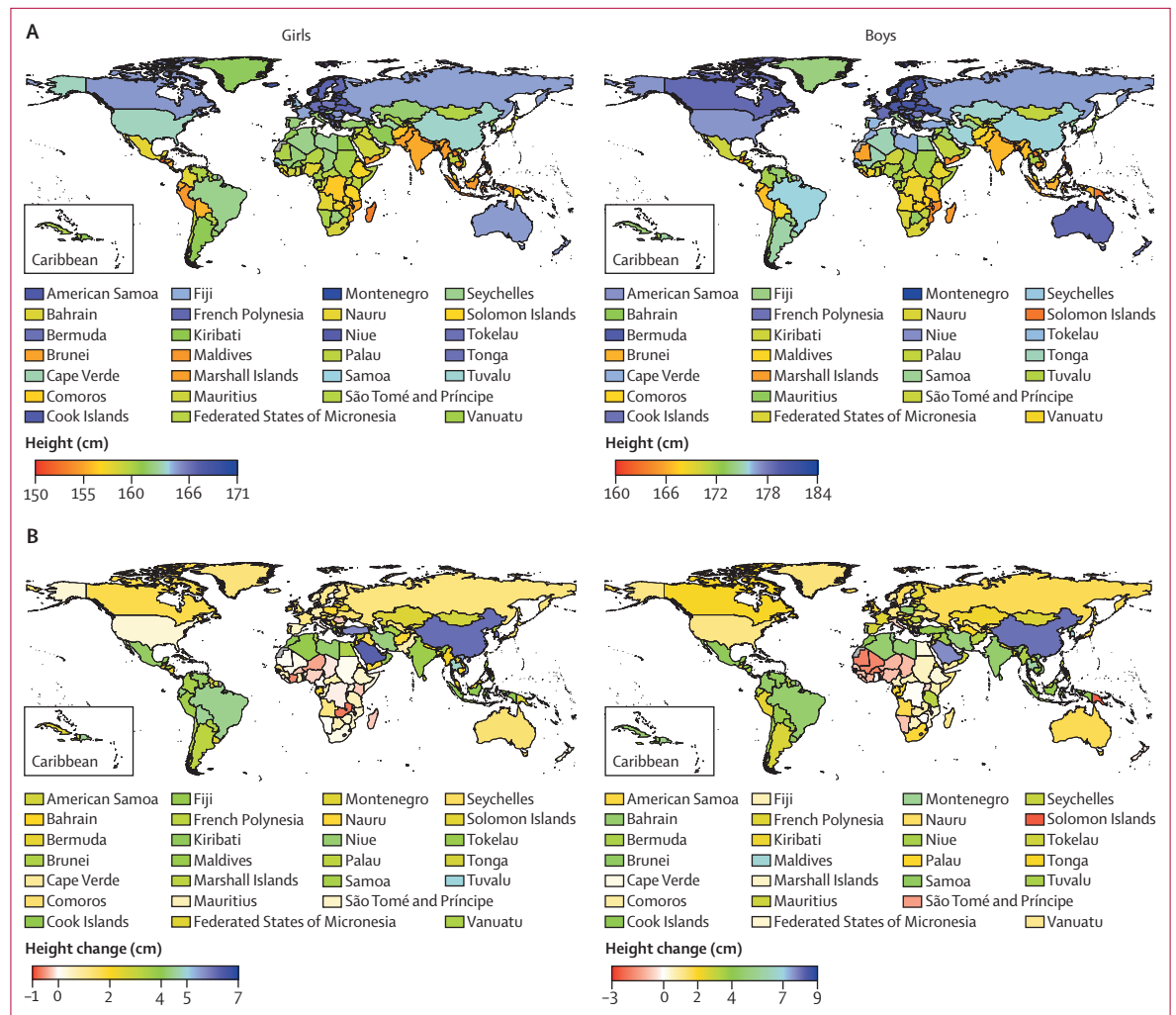


Figure 1: Height and height change by country and territory
(A) Mean height of 19-year-olds in 2019. (B) Change in mean height of 19-year-olds from 1985 to 2019.

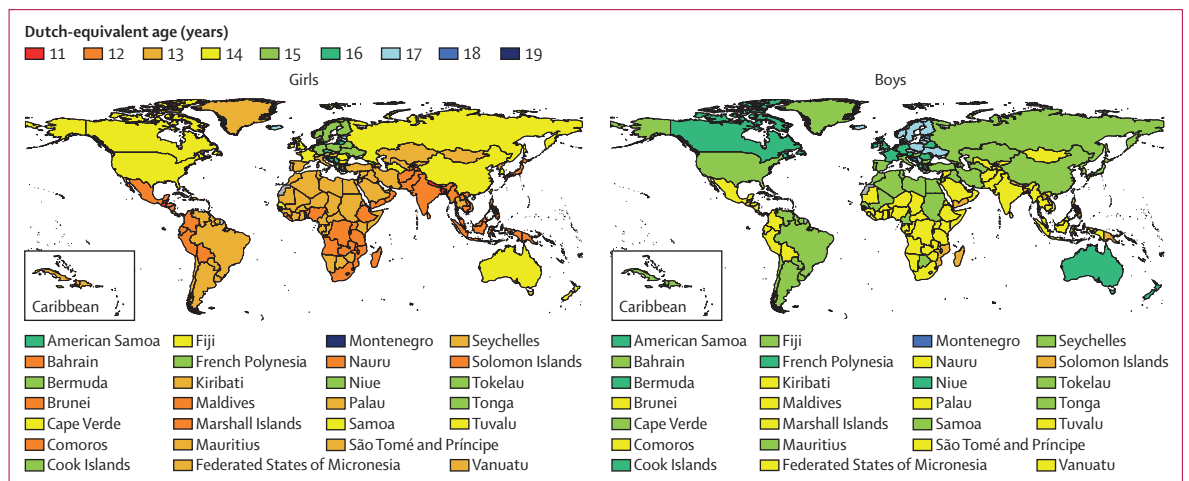


Figure 2: Growth gap for 19-year-olds in 2019 by country and territory
The growth gap is the difference between 19 years and the age at which a Dutch girl or boy, who had the highest height in the world, achieved the height of 19-year-olds in different countries.

especially in boys. However, the largest gains in height over the past 3·5 decades were those in some emerging economies, including China (largest gain for boys and third largest for girls) and South Korea (third largest for boys and second largest for girls), and through parts of southeast Asia, the Middle East and north Africa, and Latin America and the Caribbean. Nonetheless, how much mean height changed from 1985 to 2019 varied substantially, even within this group of countries. For example, gains in mean height at age 19 years in China were larger than in India by 3·5 cm (95% CrI 1·8–5·1) for boys and 2·3 cm (0·9–3·7) for girls. By contrast with emerging economies, the height of children and adolescents, especially boys, has on average stagnated or become shorter since 1985 in many countries in sub-Saharan Africa.¹⁰

Pacific island countries in Oceania had the highest mean BMI in the world in 2019, surpassing 28 kg/m² for 19-year-olds in many of these nations (figure 3A).

Late-adolescence BMI was also high for boys and girls in Middle Eastern and north African countries such as Kuwait and Bahrain; in Caribbean islands such as the Bahamas; in Chile, the USA, and New Zealand; and, for girls, in South Africa. The mean BMI of 19-year-old boys and girls was lowest (approximately 21 kg/m² or lower) in countries in south Asia (eg, India and Bangladesh), southeast Asia (eg, Timor-Leste), and east and central Africa (eg, Ethiopia and Chad), as was it for 19-year-old girls in Japan and some central European countries (eg, Romania and Bosnia and Herzegovina). The highest and lowest worldwide BMIs were approximately 9–10 kg/m² apart, equivalent to about 25 kg of weight.

Change in late-adolescence BMI from 1985 to 2019 ranged from small changes (less than 0·5 kg/m²) in both sexes in Japan and some European countries (eg, Italy, Russia, and Denmark) and, for girls, in some central Asian (eg, Armenia) and sub-Saharan African countries, to increases higher than 3 kg/m² in Malaysia and some

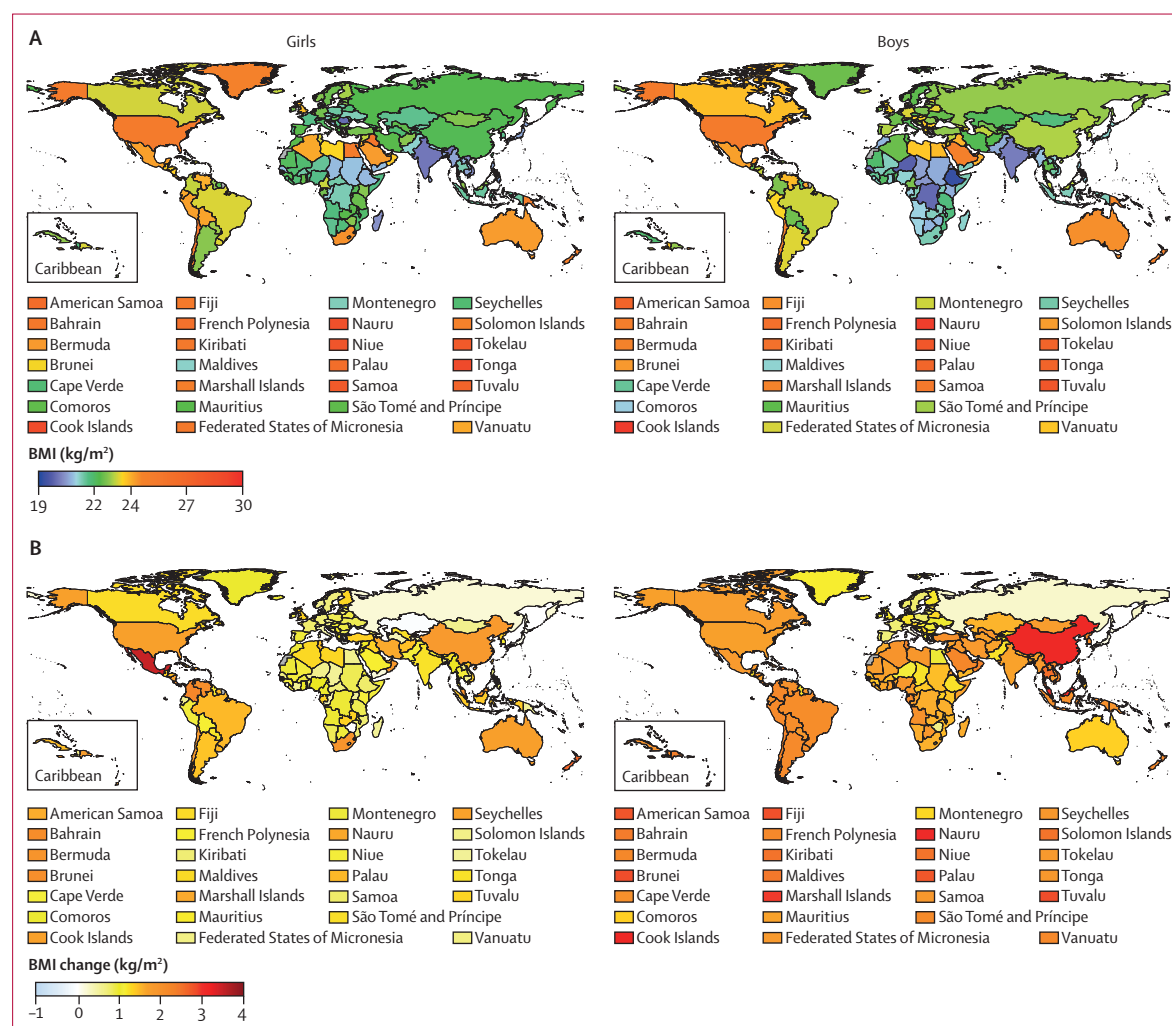


Figure 3: BMI and BMI change by country and territory

(A) Mean BMI of 19-year-olds in 2019. (B) Change in mean BMI of 19-year-olds from 1985 to 2019. BMI=body-mass index.

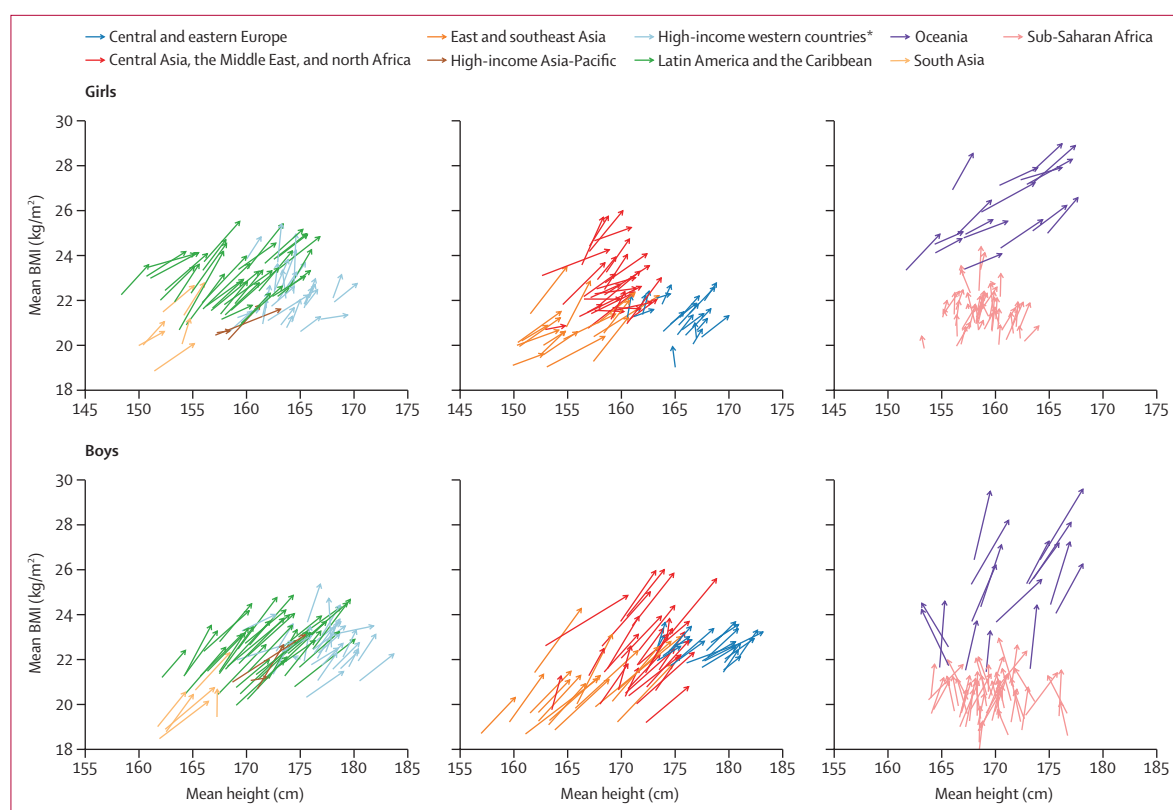


Figure 4: Combined change from 1985 to 2019 in mean height and mean BMI of 19-year-olds

Each arrow shows one country. For each country, the arrow begins at mean height and BMI values in 1985 and ends in mean height and BMI values in 2019. Each arrow colour refers to countries in one region. BMI=body-mass index. *Countries in northwestern Europe, southwestern Europe, and English-speaking high-income countries (Australia, Canada, Ireland, New Zealand, the UK and the USA).

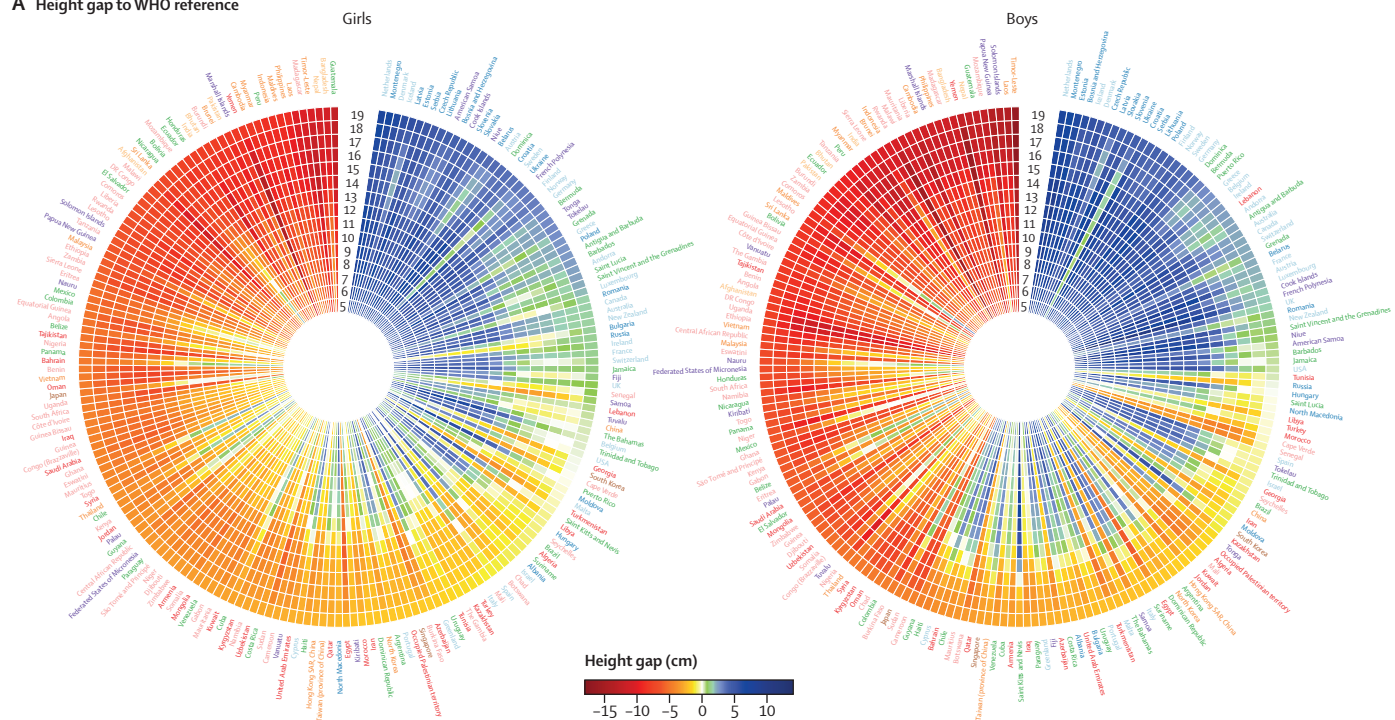
countries in Oceania for both sexes, in China for boys, and in Mexico for girls (figure 3B).

From 1985 to 2019, 19-year-old girls in some countries in central Asia (eg, Armenia and Azerbaijan) and 19-year-old boys in some European countries (eg, Portugal, Denmark, Poland, and Montenegro) had moderate-to-large gains in height alongside small or no increases in BMI (figure 4). Meanwhile, children grew much taller in some countries (eg, girls in South Korea, Turkey, Vietnam, and Saudi Arabia), while their BMI increased about the same as the global median. Both these trends were healthier than those of boys and girls in much of sub-Saharan Africa and in New Zealand and the USA, boys in Malaysia and some countries in Oceania, and girls in Mexico, where little or no height gain occurred, much larger weight was gained, or both, relative to other countries.

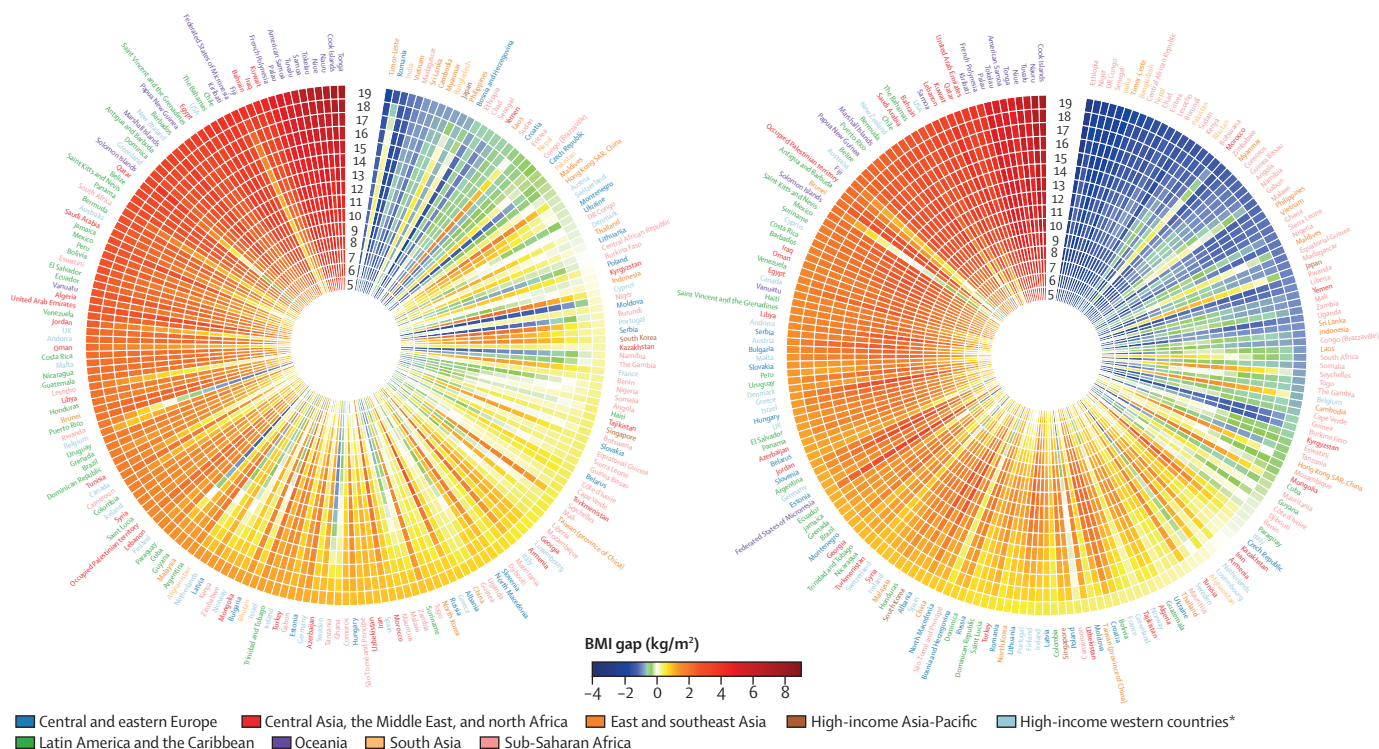
Boys born in 2000 (ie, who were aged 19 years in 2019) gained from 53.4 cm to 71.3 cm of height from their 5th to 19th birthday in different countries (appendix pp 96–296); for girls born in the same year, height gain from their 5th to 19th birthday ranged from 43.8 cm to 55.5 cm in different countries. We compared the mean height and mean BMI of children born in 2000 in each country with the median of the

respective WHO growth reference¹² at each age from 5 to 19 years (figure 5A). This comparison showed that, in many countries, mean height throughout late childhood and adolescence was lower than the median of the WHO growth reference (figure 5A, appendix pp 297–98). Exceptions to this pattern were much of Europe and a few countries in the Caribbean and Polynesia (eg, Dominica for boys and girls and French Polynesia for girls), where mean height throughout late childhood and adolescence was higher than the median of the WHO reference by about 3 cm or more. Elsewhere, either height advantage (ie, having mean height higher than the WHO reference median) at 5 years was diminished or reversed as children grew older, or height disadvantage (ie, having mean height lower than the WHO reference median) increased. This progressive falling behind as children grew older was especially noticeable in middle-income countries in Latin America and the Caribbean (eg, Chile and Uruguay), the Middle East and north Africa (eg, United Arab Emirates), and sub-Saharan Africa (eg, Mauritius and South Africa), where children had optimal height at age 5 years, but by the time they reached age 19 years, their height was shorter than the median of the WHO reference, by about 2 cm or more. A small number of

A Height gap to WHO reference

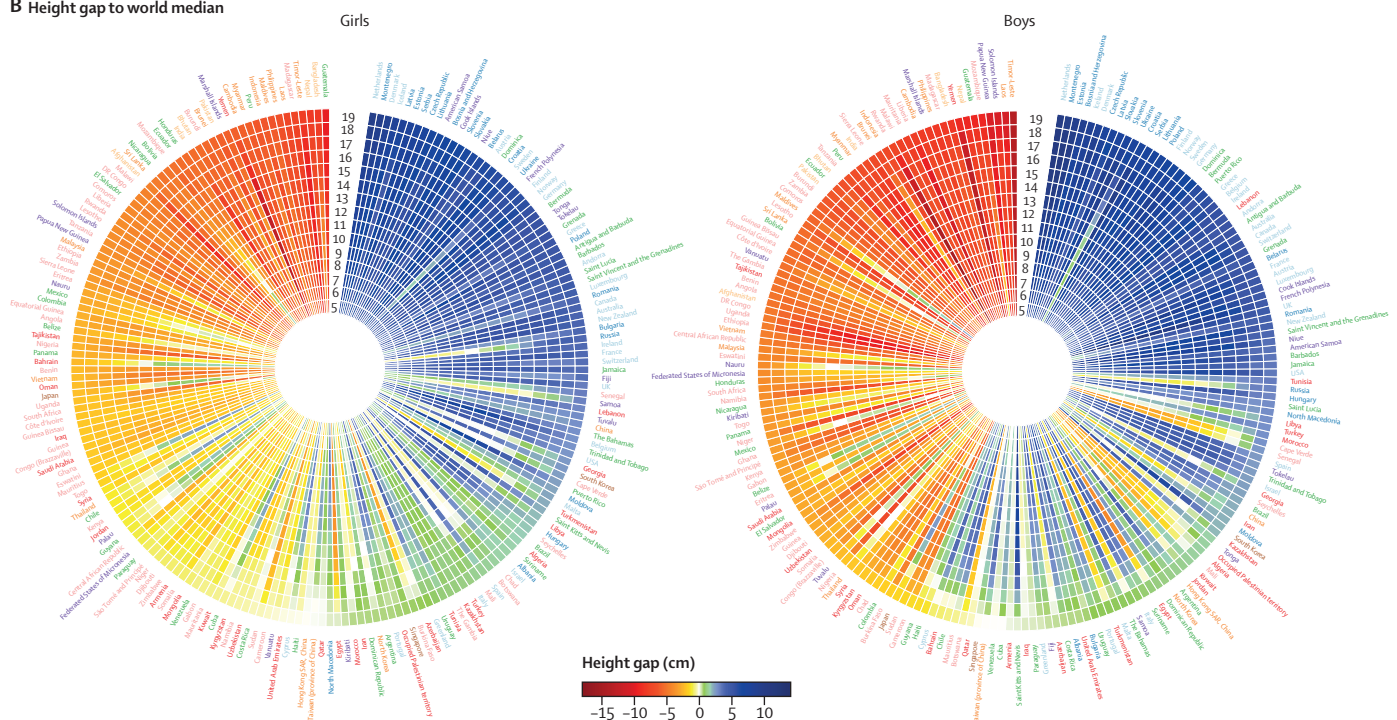


BMI gap to WHO reference

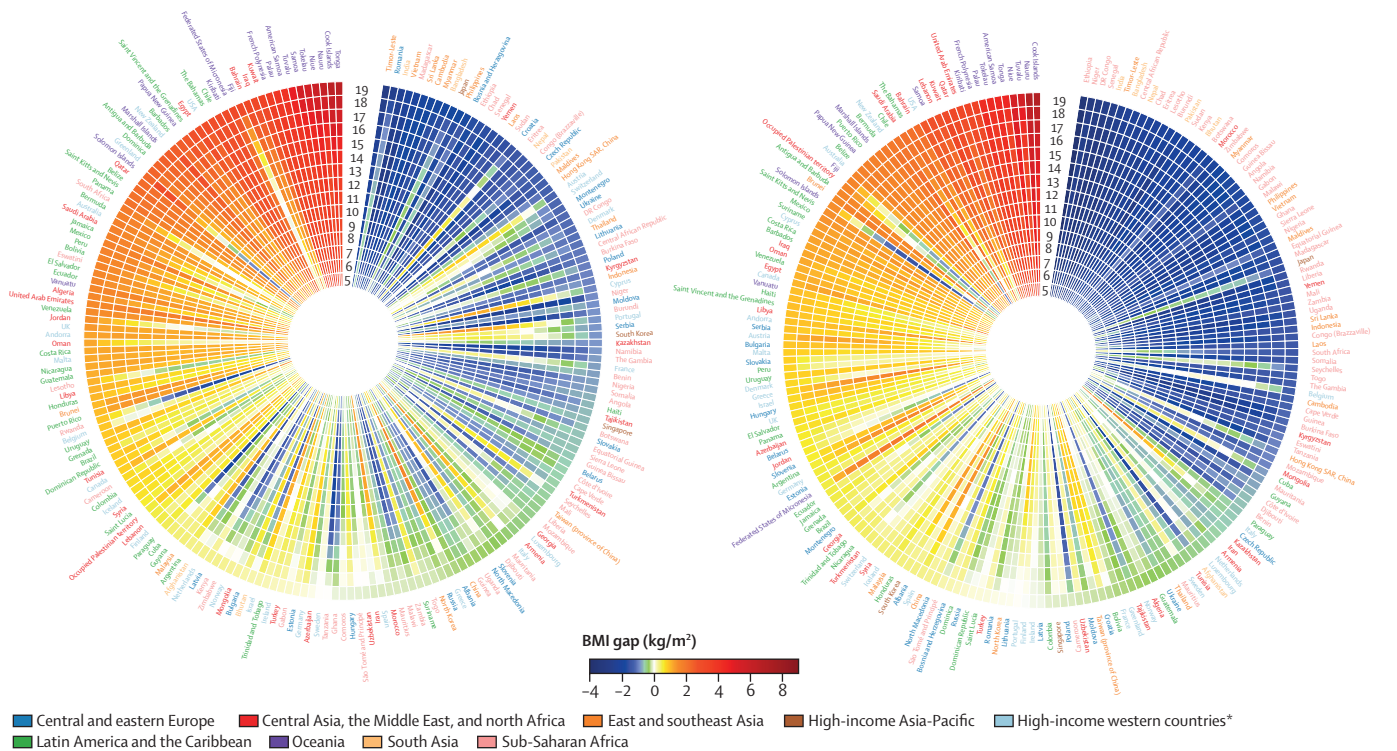


(Figure 5 continues on next page)

B Height gap to world median



BMI gap to world median



countries (eg, Russia for boys and girls and Iran for boys) slightly reduced the gap to the WHO reference median during late childhood and adolescence.

For BMI, the deficit relative to the WHO reference median at age 5 years, which was seen mainly in sub-Saharan Africa and south and southeast Asia, generally became smaller or disappeared as children grew to adolescence and reached age 19 years (figure 5A). For girls in South Africa and girls and boys in Canada, China, and some countries in Oceania, the Middle East and north Africa, and Latin America and the Caribbean, mean BMI was similar to the WHO reference median for 5-year-old children, but exceeded the WHO reference median as the children became older.

Comparing height and BMI in each country with the median of all countries (figure 5B) showed that children and adolescents in some countries had a consistent height advantage or disadvantage relative to those in other countries at every age. This was especially the case for countries at the top (eg, the Netherlands, Denmark, Montenegro, Estonia, and Iceland) and the bottom (eg, Timor-Leste, Laos, Nepal, Yemen, and Guatemala) of the global ranks at age 19 years. For other countries, children's height caught up with or fell behind their comparators during school ages. For example, children in some European countries (eg, girls in Belgium and boys in Austria) and Latin America and the Caribbean (eg, girls in Puerto Rico and boys in Barbados) had about the same height as Dutch children at age 5 years, but progressively fell behind such that, by the time they were 19 years old, they were more than 5 cm shorter than Dutch adolescents. By contrast, the height of children and adolescents in Latvia, Czech Republic, Morocco, and Iran progressively improved relative to others as they approached age 19 years.

When age-specific mean BMI was compared with the global median (figure 5B), whether a country had low (eg, countries in south and southeast Asia) or high (eg, the USA, Chile, and countries in Oceania) mean BMI relative to others, persisted more than was the case for height. Nonetheless, some differences in age trajectories of BMI occurred across countries. For example, girls and boys in some European countries (eg, Italy,

France, and Croatia), Japan, and Seychelles progressively moved towards healthier BMIs relative to other countries, and the difference between their BMI and the global median changed from positive to negative. By contrast, girls and boys in countries such as Kuwait, Bahrain, Fiji, Jamaica, and Mexico; and girls in South Africa and New Zealand had a progressively higher BMI relative to the global median as they became older.

Discussion

We identified highly variable age trajectories and trends over time in the height and BMI of school-aged children and adolescents across countries and territories. These cross-country differences show that childhood and adolescence are crucial periods in differentiating countries in terms of how they shape these determinants of lifelong health.

Our results are consistent with findings from both studies of adolescents in individual countries and global studies of adult height, which show substantial variation in how much height has changed throughout the world.¹⁴ One study,¹⁵ assessing cross-sectional height in 53 community-based samples, found substantial cross-population variation in height differences from ages 10–17 years, which is consistent with our findings on age trajectories. Our results are also consistent with previous global analyses¹¹ in terms of regions and countries with the highest and lowest BMI, but previous studies had not considered age trajectories.

Our study has strengths in scope, data, and methods: we presented novel estimates of height in school-aged children and adolescents for all countries in the world, and we did so alongside estimates of BMI. We used an unprecedented scale of population-based data from 193 countries and territories covering approximately 99% of the world's population, while maintaining a high standard of data representativeness and quality. Data were analysed according to a consistent protocol, and the characteristics and quality of data from each country were rigorously verified through repeated checks by NCD-RisC members. We used a statistical model that accounted for non-linear changes in height and BMI throughout childhood and adolescence, and we used all available data while giving more weight to national data than to subnational and community sources.

As with all global analyses, our study has some limitations. Despite our extensive efforts to identify and access worldwide population-based data, some countries, especially those in the Caribbean, Polynesia and Micronesia, Melanesia, and sub-Saharan Africa, had fewer data sources than in other regions. The scarcity of data is reflected in the larger uncertainty of our estimates for these countries and regions compared with those for other countries. Of the studies used, less than half had data for children aged 5–9 years compared with nearly 90% with data for children aged 10–19 years, which increases the uncertainty of findings for the

Figure 5: Age trajectory of height and BMI for 19-year-olds in 2019

Mean height and BMI of 19-year-olds in 2019 (ie, those born in 2000) at each age from 5 to 19 years compared with the median of the WHO growth reference¹² (A) and the world median (B). Each cell represents the difference between the height or BMI of children and adolescents in one country and the median value for a given age of the WHO growth reference (A) and all countries (B). Countries are ordered by decreasing height or increasing BMI in adolescents at age 19 years in 2019. The median of the WHO growth reference and world median are presented in the appendix (pp 90–93). Results reported as Z scores of the WHO growth reference are presented in the appendix (pp 297–98). A comparison of height and BMI gap between boys and girls is presented in the appendix (pp 299–300). BMI=body-mass index. SAR=Special Administrative Region. *Countries in northwestern Europe, southwestern Europe, and English-speaking high-income countries (Australia, Canada, Ireland, New Zealand, the UK and the USA).

younger age groups. BMI is an imperfect measure of the extent and distribution of fat in the body, but it has the major advantage of having consistent and comparable data in many population-based surveys, especially compared with measures such as body fat measured by dual-energy x-ray absorptiometry (DEXA), which is complex and costly and cannot be used in surveys. A systematic review reported that BMI and DEXA-measured body fat were highly correlated.¹⁶ We compared height and BMI in each country with the median of the WHO growth reference.¹² Although the reference is the current international comparison tool,¹⁷ unlike that of children younger than 5 years, it is not based on a multicountry sample of predominantly healthy and well-nourished children.¹² Consequently, the reference might be affected by slower growth as the sample children grew older.¹⁸ Future studies should also evaluate the socioeconomic and geographical patterns of height and BMI in these ages, as has been done for children younger than 5 years and adults.^{19,20}

Several factors that interact throughout childhood and adolescence, and possibly across generations, might be responsible for the heterogeneous worldwide age trajectories and trends of height and BMI.²¹ First, there is an important genetic component to height^{22,23} and, to a lesser extent, to BMI²⁴ within populations. However, genetics explains a small part of the variation across countries or the changes over time, especially for BMI.^{25–28} That genetics has a small role in height and BMI at the population level relative to nutrition and environment is also supported by the finding that the height of migrant descendants typically converges to the height of their new country within a few generations.^{29–31} Second, some of the observed differences in height and BMI might be intergenerational or due to exposures and experiences during pregnancy, mediated through birth length and weight.²¹ Third, the age of puberty onset, which is influenced by diet, physical activity, and weight gain during childhood, might affect height gain during the adolescent growth spurt and in late adolescence.³² Although some studies have found a negative association between age of pubertal onset and final height,³³ others have found that age of pubertal onset does not affect final height, because an earlier puberty onset might be compensated by a more intense or longer period of peak height velocity.³⁴ No comparable global data exist on age at menarche and timing of pubertal growth, but national data indicate substantial changes in some countries. Finally, all of these pathways are influenced by food and nutrition,^{28,35,36} including energy balance, and adequacy and quality of nutrients, especially proteins, fats, and micronutrients.^{18,21,37} There is also an important effect from the occurrence and treatment of infections, which itself is influenced by water and sanitation, and whether episodes of infections are effectively treated in a timely manner. Similarly, physical activity at home and school can influence BMI.

Fully establishing the drivers of the observed height and BMI trajectories and trends requires data on these determinants and their distributions in different countries.

Our findings on the heterogeneous age trajectories and time trends of height and BMI in late childhood and adolescence raise the need to rethink and revise two common features of global health and nutrition programmes. First, we need to overcome the disconnect in research and practice between reducing undernutrition, particularly short stature, and preventing and managing overweight and obesity.^{11,19,21} Second, the finding that children in some countries grow healthily to age 5 years but do not continue to do so during school years shows an imbalance between investment in improving nutrition and growth before age 5 years and doing so in school-aged children and adolescents.³⁸ Therefore, our findings should motivate policies and interventions at home, at school, in the community, and through the health system to support healthy growth during the entire period from birth to adolescence through enhanced nutritional quality, healthier living environment, and provision of high-quality preventive and curative care. These measures include agricultural and food system policies³⁹ that increase the availability and reduce the cost of nutritious foods that help children grow taller without gaining excessive weight for their height; (conditional) cash transfers and food vouchers towards nutritious foods for low-income families; free healthy school meal programmes; fiscal and regulatory policies that restrict the consumption of unhealthy foods, especially processed carbohydrates; the provision of affordable healthy housing, clean water, and sanitation; and the provision of facilities for play and sports in the community and at school. Taking these actions would enable children to grow taller without gaining excessive weight, with lifelong benefits for their health and wellbeing.

Contributors

ARM, ZB, RB, and ME designed the study. Members of the Country and Regional Data Group collected and re-analysed data and checked pooled data for accuracy of information about their study and other studies in their country. ARM, BZ, and MS led the data collection. ARM led the statistical analysis with input from BZ, JB, JEB, CJP, and ME and prepared results. Members of the Pooled Analysis and Writing Group contributed to study design, collated data, and checked all data sources in consultation with the Country and Regional Data Group. ARM and ME wrote the first draft of the report with input from other members of the Pooled Analysis and Writing Group. Members of the Country and Regional Data Group commented on the draft report. ME oversaw research. The authors alone are responsible for the views expressed in this Article and they do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated.

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